IECM Overview

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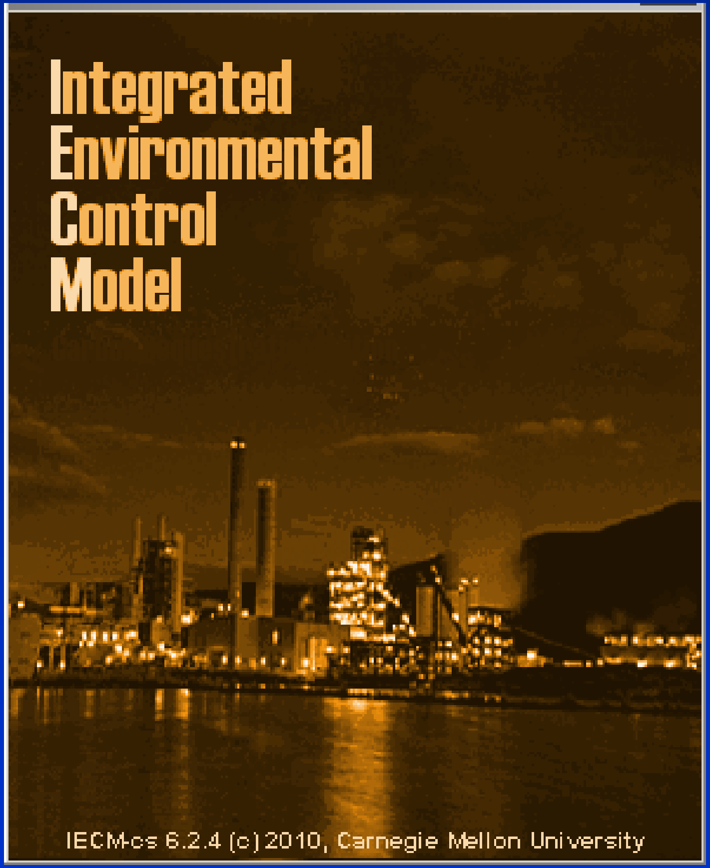
The Integrated Environmental Control Model (IECM)

- A desktop/laptop computer simulation model developed for DOE/NETL
- Provides systematic estimates of performance, emissions, costs, and uncertainties for preliminary design of:
  - PC, IGCC, and NGCC plants
  - All flue/fuel gas treatment systems
  - CO_2 capture and storage options (pre- and post-combustion, oxy-combustion; transport, storage)
- Free and publicly available at: **www.iecm-online.com**



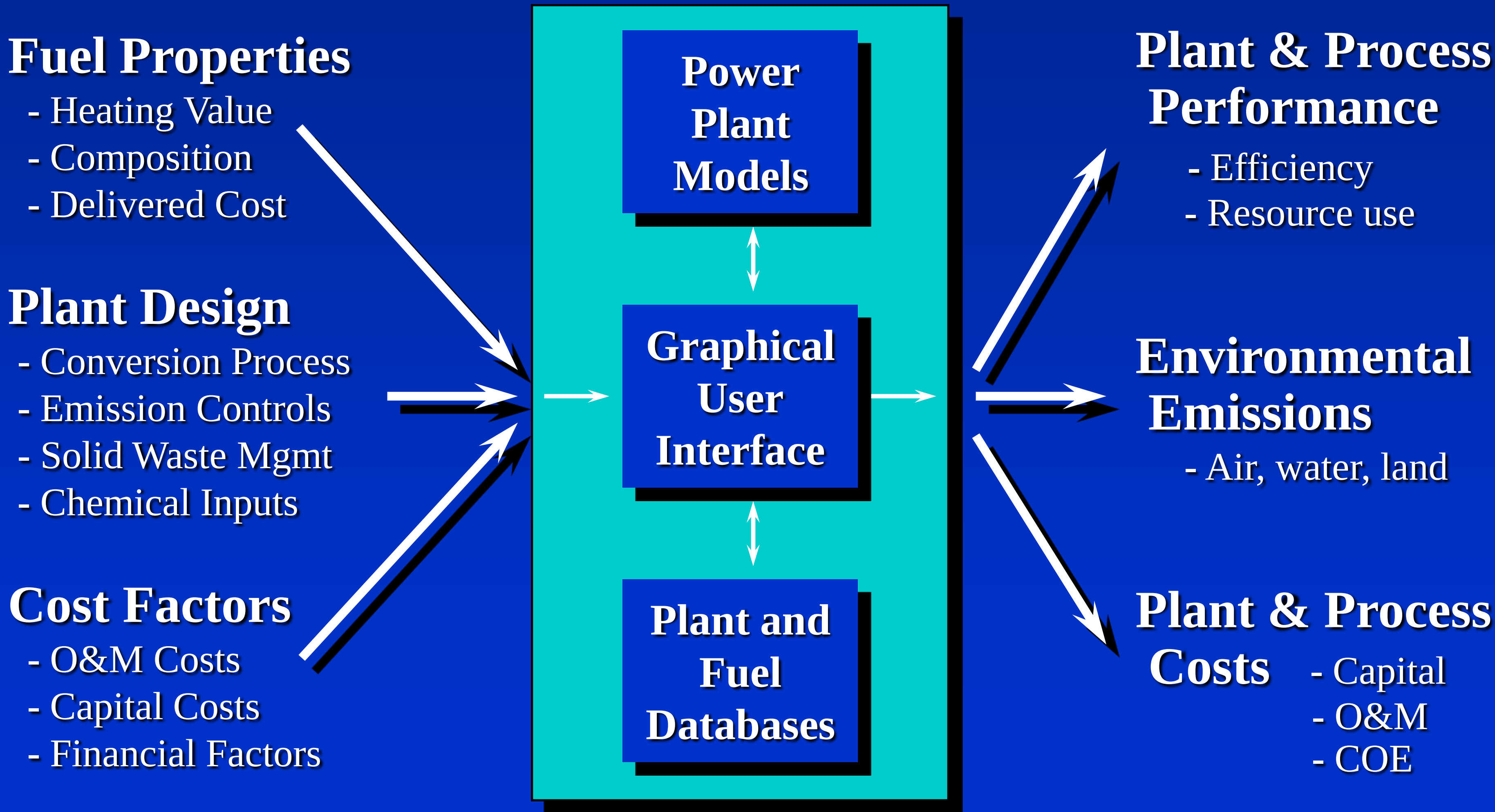
Highlights of IECM Development

- Originally developed to assess advanced technologies for SO_2, NO_x and Hg capture at PC plants
- Expanded under the DOE Carbon Sequestration Program to include current options for CO_2 capture (as well as transport and storage) at PC, IGCC, and NGCC plants
- Major update completed in November 2009 based on DOE/NETL Bituminous Baseline Study; IECM version 6.2.4 posted on Web in spring 2010
- Initiated new contracts in September 2010 and January 2011 to model several advanced CO_2 capture processes

IECM Modeling Approach

- Systems Analysis Approach
- Process Performance Models
- Engineering Economic Models
- Advanced Software Capabilities
  - Probabilistic analysis capability
  - User-friendly graphical interface
  - Easy to add or update models

IECM Software Package



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IECM Technologies for PC Plants

(excluding CO_2 capture, transport, and sequestration)

Boiler/Turbine Types
- Subcritical
- Supercritical
- Ultra-supercritical

Furnace Firing Types
- Tangential
- Wall
- Cyclone

Furnace NO_x Controls
- LNB
- SNCR
- SNCR + LNB
- Gas reburn

Flue Gas NO_x Removal
- Hot-side SCR

Mercury Removal
- Carbon/sorbent injection

Particulate Removal
- Cold-side ESP
- Fabric filter
  - Reverse Air, Pulse Jet

SO_2 Removal
- Wet limestone
  - Conventional, Forced oxidation
  - Additives
- Wet lime
- Lime spray dryer

Solids Management
- Ash pond, Landfill, Co-mixing
- Byproducts (for export)

Cooling and Wastewater Systems
- Once-through cooling
- Wet cooling tower
- Dry cooling tower
- Chemical treatment
- Mechanical treatment

IECM Technologies for IGCC Plants

(excluding CO_2 capture, transport and sequestration)

Air Separation Unit
- Cryogenic

Slurry Preparation

Coal Pretreatment

Gasification
- Slurry-feed gasifier (GE-Q)
- Dry-feed gasifier (Shell)

Syngas Cooling and Particulate Removal System

Mercury Removal
- Activated carbon

H_2S Removal System
- Selexol
- Sulfinol

Sulfur Recovery System
- Claus Plant
- Beavon-Stretford Unit

Gas Turbine
- GE 7FA
- GE 7FB

Heat Recovery Steam Generator

Steam Turbine

Boiler Feedwater System

Process Condensate Treatment

Auxiliary Equipment

Cooling Water System
- Once-through
- Wet cooling tower
- Air cooled condenser

IECM Technologies for CCS

- CO_2 Capture Options
  - *PC :* - Amine system (post-combustion)
    (w/optional auxiliary NG boiler)
    - Oxy-combustion w/ flue gas recycle
  - *NGCC :* - Amine system (post-combustion)
  - *IGCC :* - Water gas shift + Selexol (pre-combustion)

- CO_2 Transport Options
  - Pipelines (six U.S. regions)
  - Other (user-specified)

- CO_2 Sequestration Options
  - Geological: Enhanced Oil Recovery (EOR)
  - Geological: Deep Saline Formation
  - Other: User-specified (e.g., ocean, ECBM)

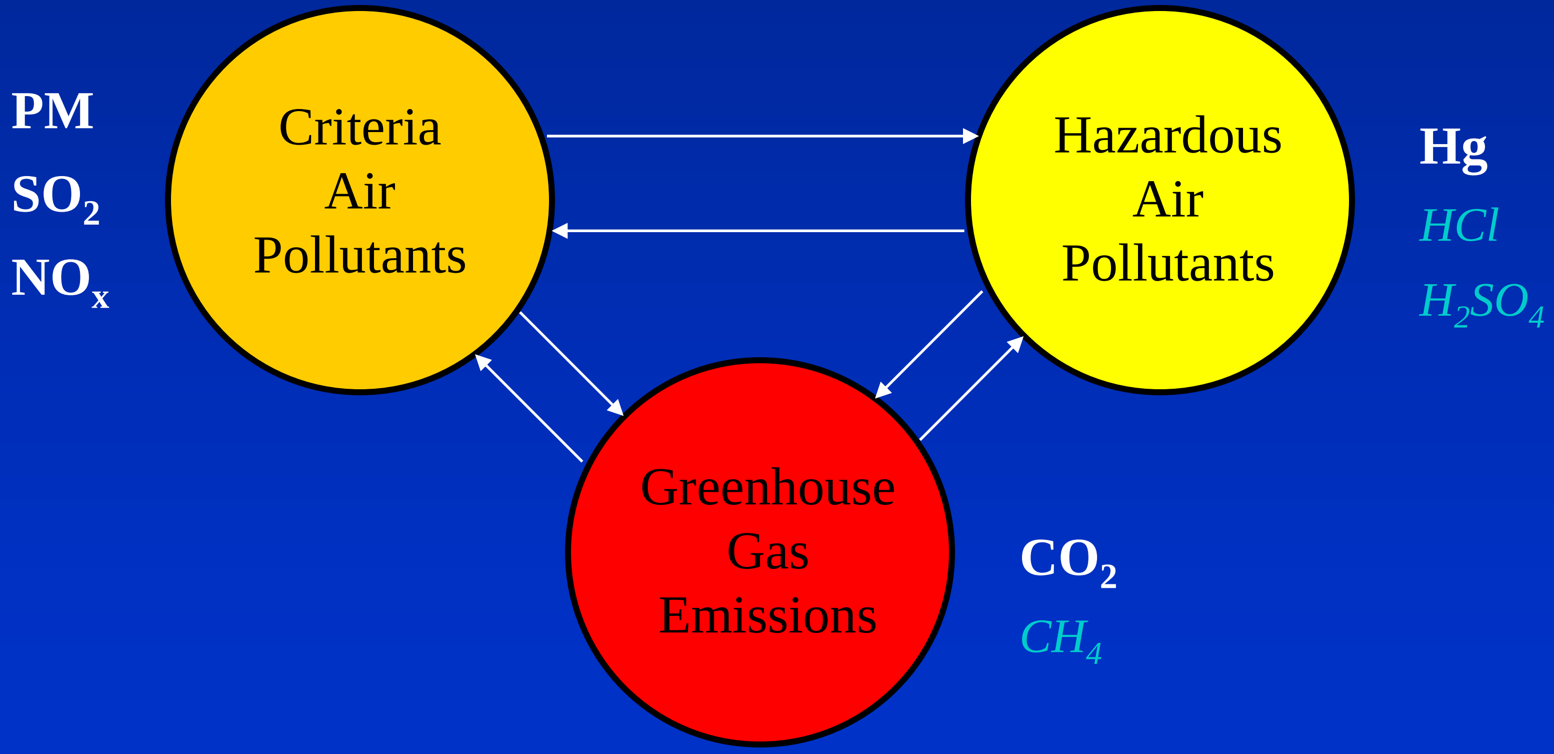
Process Performance Models

- Detailed mass and energy balances for each component and overall plant
- For components with complex chemistry and/or heat integration schemes, multi-variate regression or other reduced-order models are derived from experimental data and detailed process models
- Approximately 10-20 performance parameters for each component technology

IECM Performance Parameters for Amine Capture System

- Flue gas composition
- Flue gas temp/pressure
- CO_2 removal efficiency
- SO_2 removal efficiency
- NO_2 removal efficiency
- HCl removal efficiency
- Sorbent concentration
- Lean solvent loading
- Acid gas sorbent loss
- Sorbent oxidation loss
- Nominal sorbent makeup
- Ammonia generation
- Cooling water makeup
- Reclaimer chemical reqm't
- Flue gas pressure drop
- Fan efficiency
- Sorbent pumping head
- Pump efficiency
- Regeneration heat
- Equiv. elec. requirement
- CO_2 product pressure
- CO_2 product purity
- Compressor efficiency
- Compression energy

Models Account for Multi-Pollutant Interactions



Technology Cost Models

- Direct cost models for each major process area (typically 5-10 areas per technology) based on detailed engineering design studies
- Explicit links to process performance models via key parameters (e.g., flow rate, temp., pressure, etc.)
- Calculate total capital cost, variable O&M costs, fixed O&M costs, and annualized cost of electricity (based on EPRI TAG cost categories and methods)
- Approximately 20-30 cost elements per technology

IECM Cost Model Parameters for Amine Capture System

- Process Area Costs (12)
- Process Facilities Cost
- Eng'g. & Home Office
- General Facilities
- Contingency Costs (2)
- Interest during Construction
- Royalty Fees
- Pre-production Costs
- Inventory (startup) Cost
- Total Plant Cost
- Total Capital Reqm't

- Operating Labor
- Maintenance Labor
- Admin./Support Labor
- Maintenance Materials
- Amine Sorbent Cost
- Other Chemicals Cost
- Waste Disposal Cost
- Water Cost
- *(Power Cost)**
- CO_2 Transport Cost
- CO_2 Storage Cost

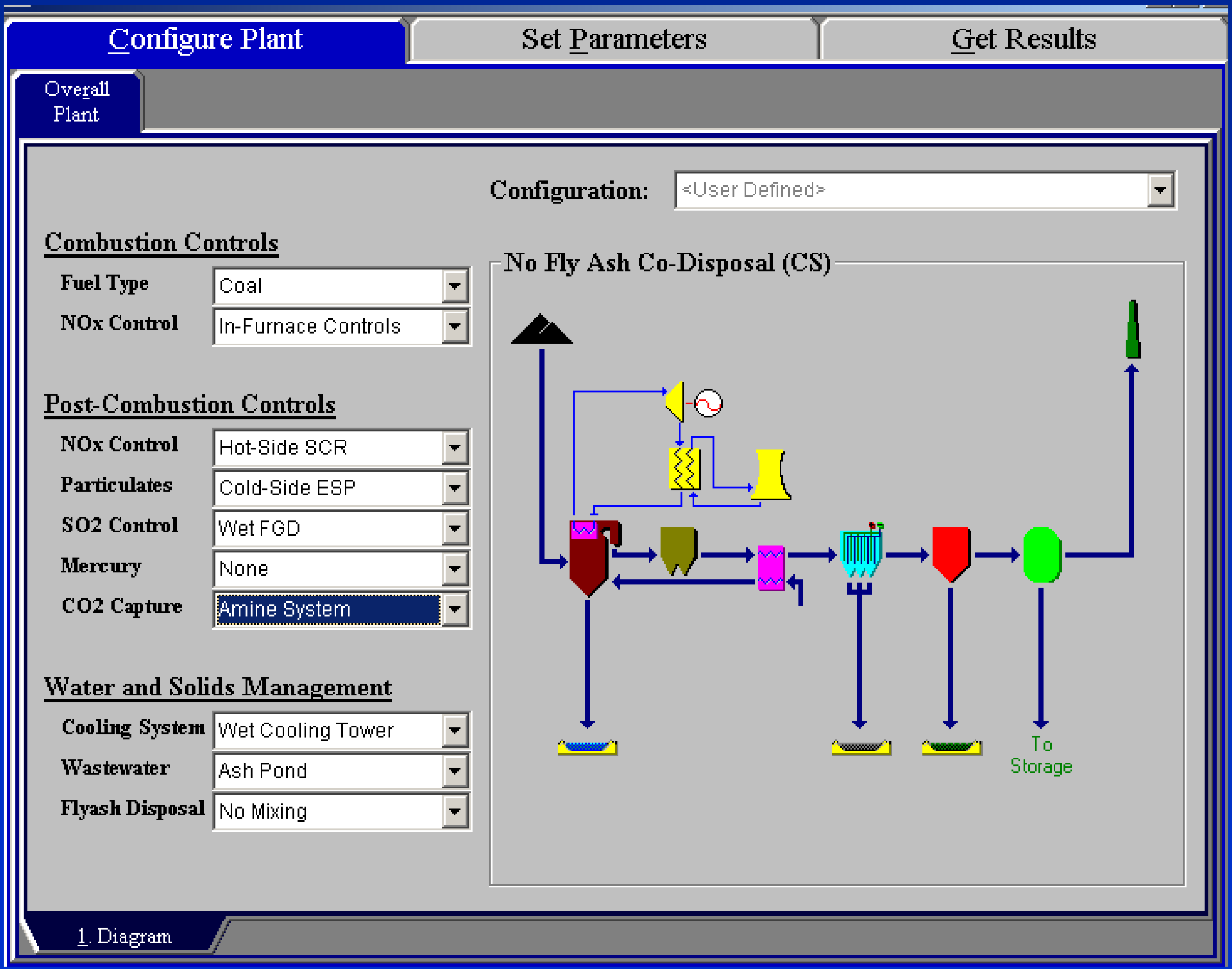
Probabilistic Capability

- Allows users to explicitly model and quantify the effects of uncertainty and/or variability on component and system performance, emissions and cost
- Values for user-selected parameters are specified as a probability distribution function (in addition to the nominal value), which is sampled using a selected method and sample size (default = median LHS)
- Results are displayed as a cumulative distribution function, yielding confidence intervals and probability of different outcomes for selected parameters

Running the Model: Three Steps

- Configure Plant
  - (from menus of component options for each plant type)
- Set Parameters
  - (or accept model defaults for system and component technical, economic, emissions, and financial parameters)
- Get Results
  - (for overall plant or individual components in graphical and/or tabular form, in English or metric units)

Configure Plant:
PC Case Study



Set Parameters:

Base Plant and CO_2 Capture System

Configure Plant | **Set Parameters** | Get Results

Overall Plant | Fuel | **Base Plant** | NOx Control | TSP Control | SO2 Control | Mercury | CO2 Capture | Water Systems | By-Prod. Mgmt | Stack

	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Gross Electrical Output	MWg		650.0	☐	100.0	2500	calc
2	Unit Type			Supercri		Menu	Menu	Sub-Critica
3	Steam Cycle Heat Rate, HHV	Btu/kWh		9876	☑	6000	1.500e+4	
4	Boiler Firing Type			Tangenti		Menu	Menu	
5	Boiler Efficiency	%		89.64	☑	50.00	100.0	
6	Excess Air For Furnace	% stoich.		20.00	☑	0.0	40.00	
7	Leakage Air at Preheater	% stoich.		10.00	☑	0.0	50.00	
8	Gas Temp. Exiting Economizer	°F		700.0		250.0	1200	
9	Gas Temp. Exiting Air Preheater	°F		300.0		150.0	500.0	
10	Percent Water in Bottom Ash Sluice	%		0.0	☑	0.0	99.99	
11								
12	Base Plant Power Requirements							
13	Coal Pulverizer	% MWg		0.5897	☑	0.0	3.000	
14	Steam Cycle Pumps	% MWg		0.1600	☑	0.0	3.000	
15	Forced / Induced Draft Fans	% MWg		1.655	☑	0.0	5.000	
16								
17	Miscellaneous	% MWg		1.040	☑	0.0	5.000	
18								

Process Type: Base Plant

1. Performance | 2. Furn. Factors | 3. Retrofit Cost | 4. Capital Cost | 5. O&M Cost

Configure Plant | **Set Parameters** | Get Results

Overall Plant | Fuel | Base Plant | NOx Control | TSP Control | SO2 Control | Mercury | **CO2 Capture** | Water Systems | By-Prod. Mgmt | Stack

	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Absorber							
2	Sorbent Concentration	wt %		30.00	☑	15.00	100.0	calc
3	Lean CO2 Loading	mol CO2/mol sorb		0.1900	☑	0.0	0.5000	calc
4	Nominal Sorbent Loss	lb/ton CO2		0.6001	☑	0.0	10.00	calc
5								
6	Liquid-to-Gas Ratio	ratio		3.072	☑	0.0	10.00	calc
7	Ammonia Generation	mol NH3/mol sorb		1.000	☑	0.0	2.000	calc
8	Gas Phase Pressure Drop	psia		1.000	☑	0.0	5.000	calc
9	ID Fan Efficiency	%		75.00		50.00	100.0	75.00
10	Makeup Water for Wash Section	% raw flue gas		0.8000		0.0	10.00	0.8000
11	Regenerator							
12	Regen. Heat Requirement	Btu/lb CO2		1516	☑	500.0	5000	calc
13	Regen. Steam Heat Content	Btu/lb steam		1373	☑	500.0	1500	calc
14	Heat-to-Electricity Efficiency	%		22.00	☑	0.0	40.00	calc
15	Solvent Pumping Head	psia		30.00		0.0	80.00	30.00
16	Pump Efficiency	%		75.00		50.00	100.0	75.00
17	Percent Solids in Reclaimer Waste	%		40.00	☑	0.0	100.0	calc
18	Capture System Cooling Duty	t H2O/t CO2		90.95	☑	0.0	200.0	calc

Process Type: CO2 Capture System

1. Config | 2. Performance | 3. Capture | 4. CO2 Storage | 5. Retrofit Cost | 6. Capital Cost | 7. O&M Cost

Get Results:
Overall Plant Performance and Cost

Configure Plant | Set Parameters | Get Results

Overall Plant | Fuel | Base Plant | NOx Control | TSP Control | SO2 Control | Mercury | CO2 Capture | Water Systems | By-Prod. Mgmt | Stack

	Performance Parameter	Value
1	Net Electrical Output (MW)	525.4
2		
3	Primary Fuel Input (MBtu/hr)	6675
4	Aux. Fuel Input (MBtu/hr)	0.0
5	Total Plant Input (MBtu/hr)	6675
6		
7	Gross Plant Heat Rate, HHV (Btu/kWh)	1.027e+4
8	Net Plant Heat Rate, HHV (Btu/kWh)	1.271e+4
9		
10	Annual Operating Hours (hours)	6575
11	Annual Power Generation (BkWh/yr)	3.454
12		
13	Net Plant Efficiency, HHV (%)	26.86
14		
15		

	Plant Electricity Requirements	Value
1	**Gross Electrical Output (MWg)**	650.0
2	**Aux. Power Produced (MW)**	
3		
4	Base Plant Use (MW)	
5		
6	Hot-Side SCR Use (MW)	
7	Cold-Side ESP Use (MW)	
8	Wet FGD Use (MW)	
9		
10	CO2 Capture System Use (MW)	
11	CO2 Transport & Storage Use (MW)	
12	Cooling Tower Use (MW)	
13	**Net Electrical Output (MW)**	
14		
15	Amine Steam Use (Elec. Equiv.) (MW)	

Process Type: Overall Plant

1. Diagram | 2. Plant Perf. | 3. Mass In/Out | 4. Solids In/Out | 5. Gas In/Out | 6. Total Cost

Configure Plant | Set Parameters | Get Results

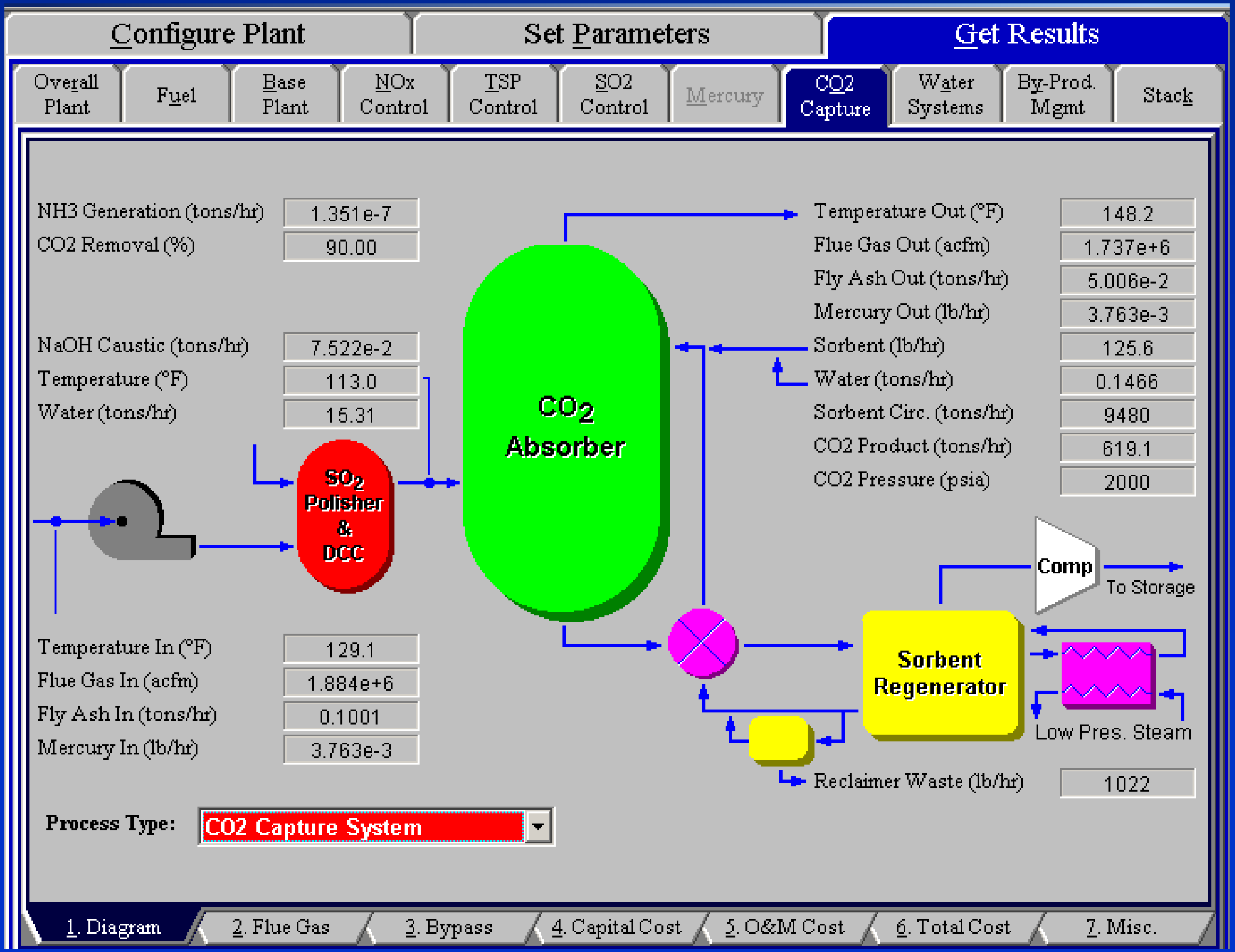
Overall Plant | Fuel | Base Plant | NOx Control | TSP Control | SO2 Control | Mercury | CO2 Capture | Water Systems | By-Prod. Mgmt | Stack

	Technology	Capital Required (M$)	Capital Required ($/kW-net)	Revenue Required (M$/yr)	Revenue Required ($/MWh)
1	Combustion NOx Control	0.0	0.0	0.0	0.0
2	Post-Combustion NOx Control	33.16	63.11	7.841	2.270
3	Mercury Control	0.0	0.0	0.0	0.0
4	TSP Control	25.12	47.82	5.460	1.581
5	SO2 Control	153.2	291.6	38.17	11.05
6	Combined SOx/NOx Control	0.0	0.0	0.0	0.0
7	CO2 Capture	451.1	858.6	101.9	29.49
8	Subtotal	662.5	1261	153.3	44.40
9	Cooling Tower	70.34	133.9	19.44	5.629
10	Base Plant	910.4	1733	168.6	48.80
11	Emission Taxes	0.0	0.0	0.0	0.0
12	Total	1643	3128	341.3	98.83
13					
14					
15					

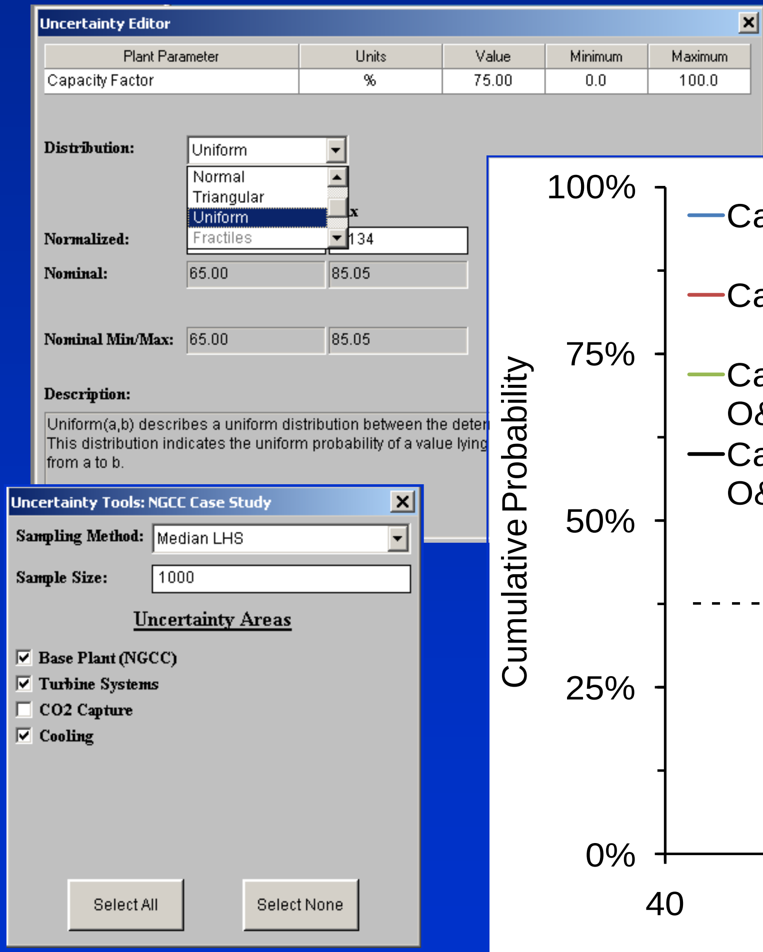
Process Type: Overall Plant **Costs are in Constant 2009 dollars.**

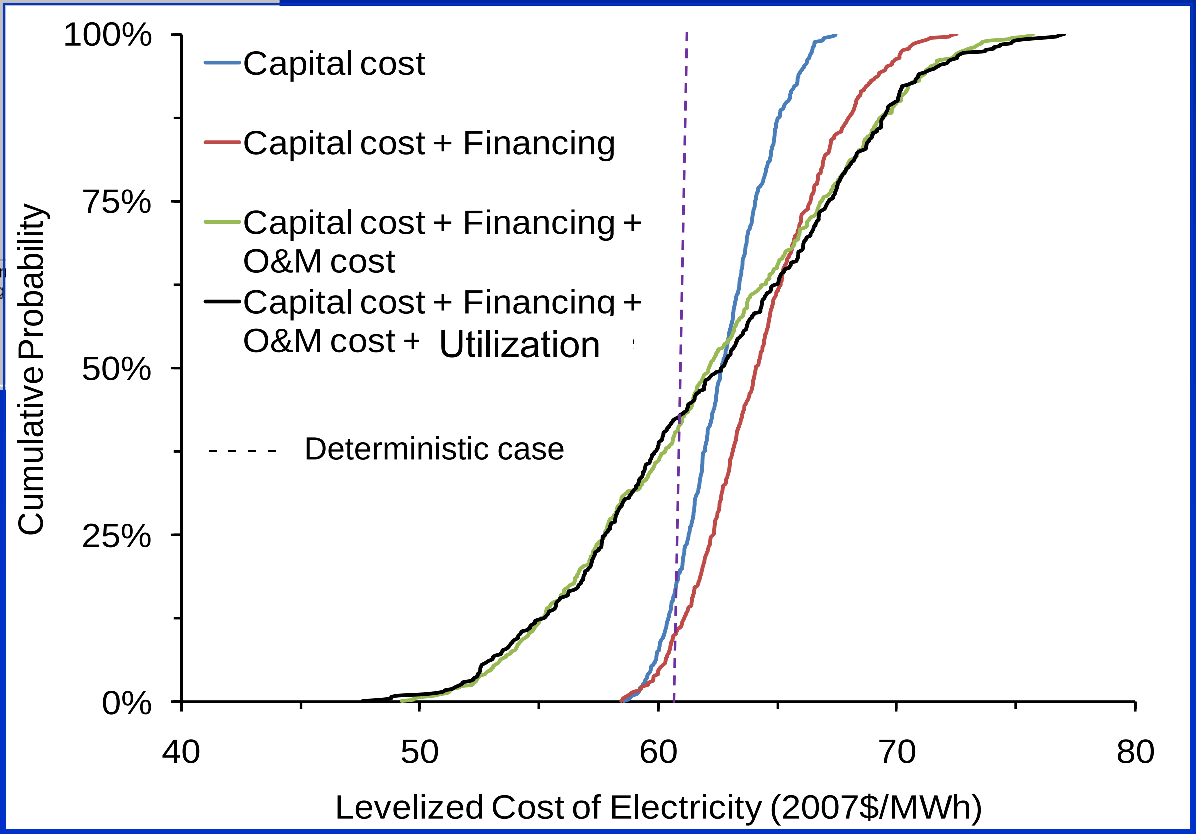
1. Diagram | 2. Plant Perf. | 3. Mass In/Out | 4. Solids In/Out | 5. Gas In/Out | 6. Total Cost | 7. Cost Summary

Get Results:
CO_2 Capture System



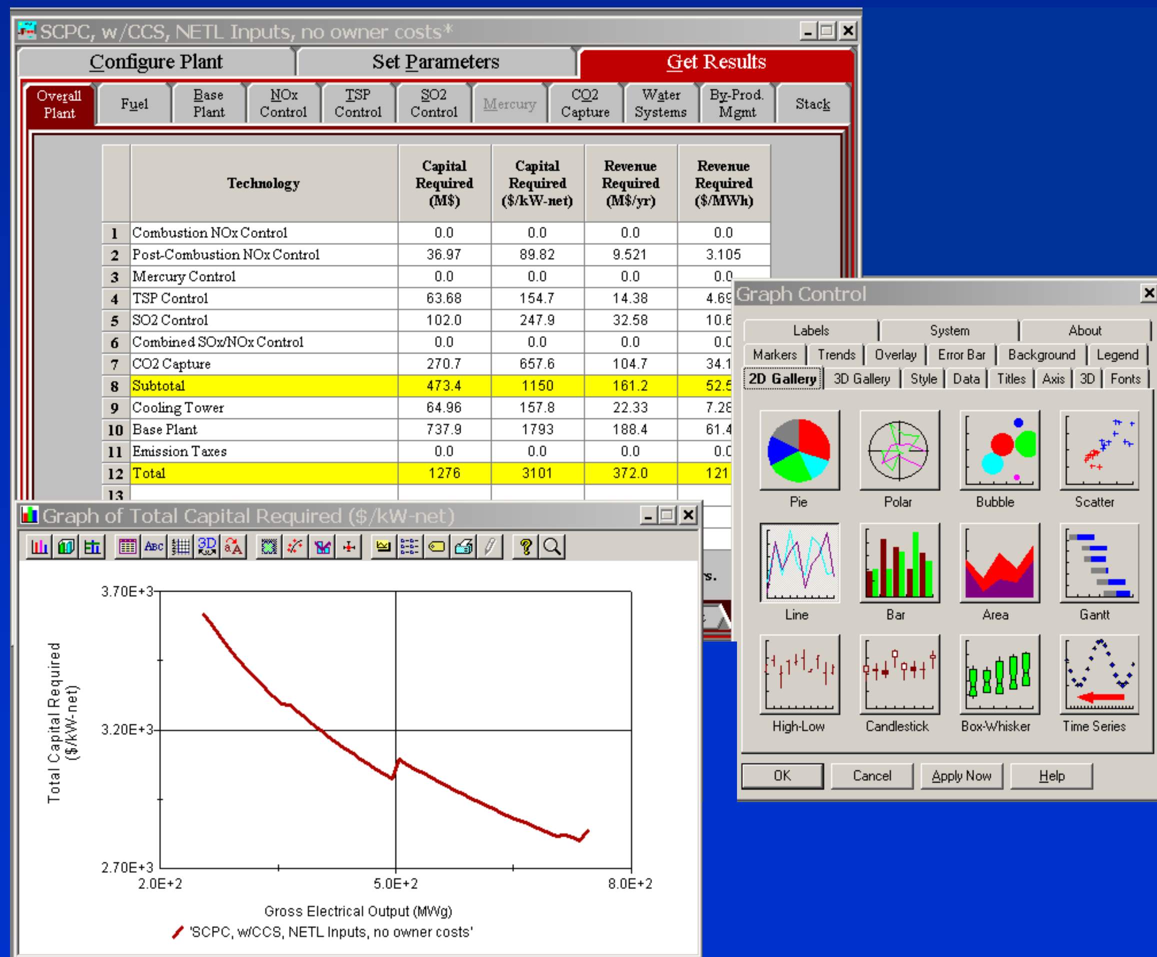
Probabilistic Results:
NGCC Case Study (no CCS)





Advanced Graphing Options

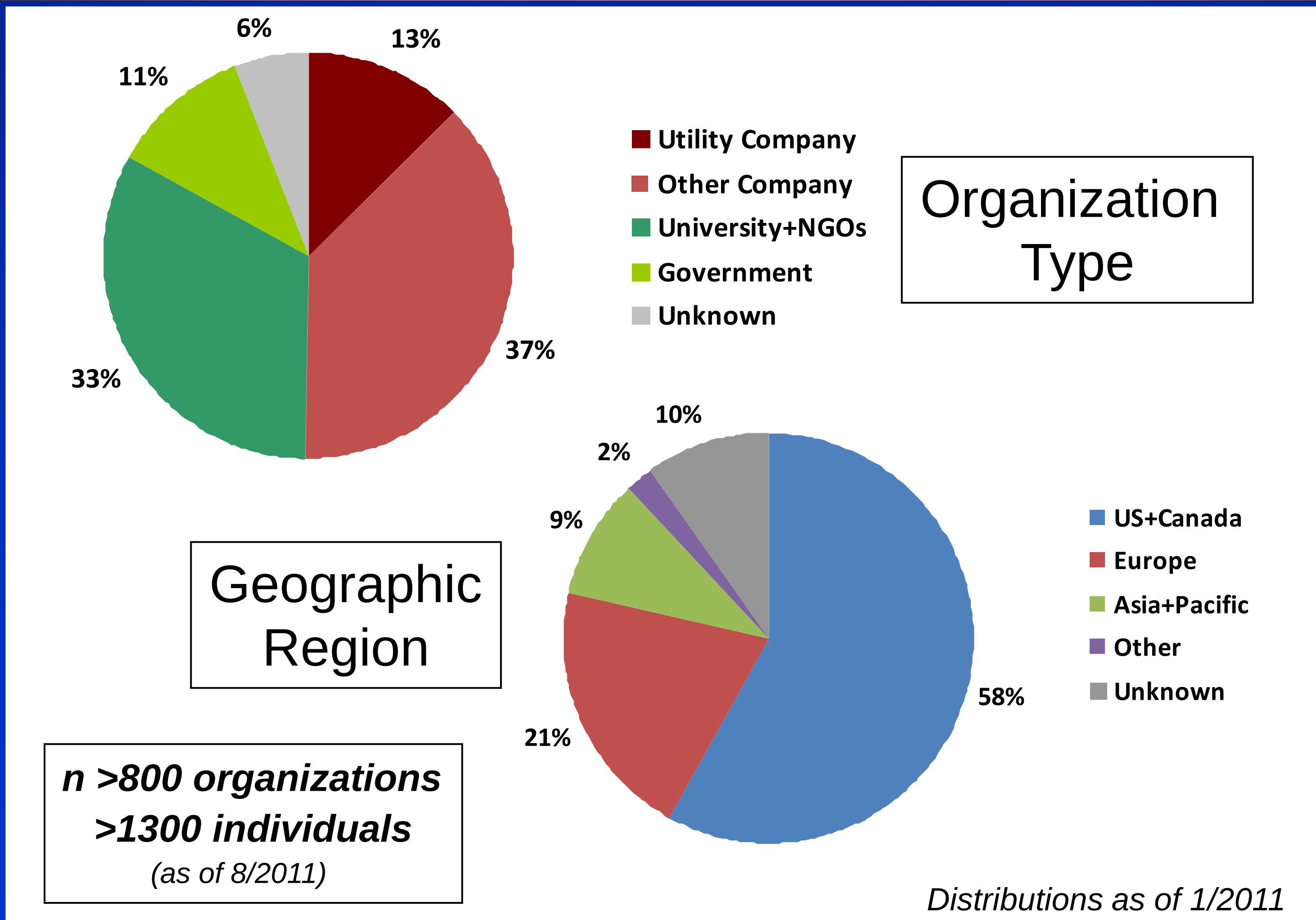
- Can easily and quickly plot any model variable as a function of any other variable
- Can display results from up to six different runs on same graph
- All graphs and data easily exported for display or further processing



Some Recent IECM Users

ABB Lummus Global, Inc.
AEP-SCR Eng'r
Air Liquide
Air Products plc
Airborne Clean Energy
Akzo Nobel FunctionalChem
Alberta Economic Dev.
Alberta Env.
Alberta Res. Council
ALCOA Power Gen., Inc.
Allegheny Energy Supply
Alliant Energy
Alstom (Switzerland)
Alstom Power Boiler GmbH
ALSTOM PowerCentrales
Alstom Power Inc.
Alstom Power Plant Lab.
American Electric Power
American Transmission Co.
Ankara University
APAT
Apogee Scientific, Inc.
ARCADIS
Argonne National Lab.
ATCO Power
Balcke-Durr GmbH
Basin Electric Power Coop.
Battelle
Battelle Northwest
Bechtel Power Corp.
Black & Veatch Corp.
BOC Gases
Boiler Systems Eng'r, E.S.O.
BP
BP Int'l Limited
BP Power Ltd.
BP Sunbury
Canada Env.
Canada Natural Resources
Canadian Clean Power Coalition
Carnegie Mellon University
Chalmers University
Chinese Academy of Sci.
Cinergy Power Gen. Services, LLC
Clean Energy Systems Inc.
Coal in Sustainable Dev., Tech Transfer
Coaltek LLC / Jupiter Oxygen Corp.
Cogentrix Energy, Inc.
Columbia University
CONSOL Energy, Inc.
Consumers Energy
Coop. Res. Centre for Greenhouse Gas
COORETEC
CQ, Inc.
Croll-Reynolds
CSEnergy
Dept. of Energy (DOE)
Dept. of Energy, Instituto de Carboquimica
Dept. of Env. and Natural Res.- NC
Dept. of Env. Protection- NJ (DEP)
Dept. of Env. Protection- PA (DEP)
Dept. of Env. Quality - VA (DEQ)
Dept. of Env. Services - NH (DES)
Detroit Edison Co.
DMCR/Dutch Ministry of Env. (VROM)
DONG Energy Gen.
Dont Inc.
Doosan Babcock Energy Ltd.
Dynegy Midwest Gen.
E. On UK
E.ON Energie AG
Edison Mission Energy
Electric Energy, Inc. (EEI)
Electric Power Gen. Assoc.
Electric Power Res. Inst. (EPRI)
Electricite de France (EDF)
Emera Inc.
Enel
AmerenUE
Energetics, Inc.
Energi E2
Energy & Env. Res. Center (EERC)
Energy & Env. Res. Corp.
Energy & Env. Strategies
Energy Res. Centre of the Netherlands
ENSR, Inc.
Env. & Renewable Energy Systems
Env. Defense
Env. Protection Agency- IL (EPA)
Env. Protection Agency (EPA)
First Energy Corp.
FirstEnergy Corp.
Florida Power & Light Co.
FLS Miljo A/S
Fluent, Inc.
Fluor Daniel Canada, Inc.
Ford
Fortum Power and Heat Oy
Fossil Energy Res. Corp.
Foster Wheeler Energia Oy
Friedman, Billings, Ramsey & Co.
Fuel Tech, Inc.
Gas Tech. Inst. (GTI)
Gassnova
GE Global Res.
GE Infra, Energy
General Electric Co.
Generators for Clean Air (GCA)
GM R&D Center
Great River Energy
Gyeongsang National University
H&W Mgmt. Sci. Consultants
Hamon Res. Cottrell, Inc.
Harvard University
Hatch Acres
Holland Board of Public Works
IEA Clean Coal Centre
IEA Env. Projects, Ltd.
IEA Greenhouse Gas R&D
IFP
Illinois Clean Coal Inst.
Illinois Dept. of Natural Resources
Illinois Inst. of Tech.
Imperial College
Indian Inst. of Tech.
Industries Limited
INERCO
Institut Teknologi Bandung (ITB)
Inst. of Applied Energy (IAE)
Inst. of Energy- EC/JRC
Intermountain Power Service Corp.
Ishikawajima-Harima Heavy Industry
Jack R. McDonald, Inc.
Japan Petroleum Exploration Co.
Kanazawa University
Kansas City Power & Light Co.
KEMA Nederland B.V.
Kennecott Energy
Kinectrics
Korea Electric Power Corp.
Korea Inst. of Energy Res.
Korea Western Power Co.
LAB SA
Lehigh University
Lincoln Electric System
Lower Colorado River Authority
MacQuarie University
Massachusetts Inst. of Tech. (MIT)
Michigan State University
MidAmerican Energy Co.
Midwest Gen. EME, LLC
Minnkota Power Coop., Inc.
Nanyang Technological University
National Energy Tech. Lab. (NETL)
National Power Plc.
Neill and Gunter
NESCAUM
New Energy & Ind. Tech. Org. (NEDO)
Nicholson & Hall Corp.
Niksa Energy Associates
NIPSCO
Niro A/S
Norman Plaks Consulting
Norsk Hydro ASA
Norsk Hydro ASA, Oil & Energy Res.
North Carolina State University
Norwegian University of Sci. and Tech.
Nova Scotia Power, Inc.
NRDC Natural Res. Defence Council
NTNU/Statoil
NTPC Limited
Ontario Power Gen.
OREC/Buckeye Power, Inc.
Pace Global Energy Services
Pacific Corp.
Pacific Northwest National Lab. (PNNL)
Pembina Inst.
Pinnacle West Energy
PIRA Energy Group
PowerGen
Powergen Power Tech.
PPL Gen., LLC
Prairie Adaptation Res. Coll.
Praxair Inc.
Princeton University
Reaction Eng'r Inst.
Reaction Eng'r Int'l
Res. Inst. of Innovative Tech. Earth
Res. Triangle Inst.
RMB Consulting & Res., Inc.
RWE Power AG
SAIC
Salt River Project
Salt River Project (SRP)
Sargent & Lundy
SaskPower
Savvy Eng'r, LLC
Sci. Applications Int'l. Corp. (SAIC)
Scientech
SFA Pacific, Inc.
Shell Chemical Co.
Shell Global Solutions Int'l
Siemens
Sierra Pacific Power Co.
Sintef Energy Res.
SNC Lavalin
Southern Co. Gen.
Southern Co. Services, Inc.
Statoil
Steven Coons Consulting
Superior Adsorbents, Inc.
Syncrude
Tampa Electric Co.
Tennessee Valley Authority (TVA)
Terra Humana Clean Tech. Eng'r Ltd.
Tetra Tech EM Inc.
Texas A&M University
Texas Municipal Power Agency
TMommer Consultants
TNO Env., Energy and Process Innov
Toshiba Corp.
TransAlta
TU Dresden
Twenty-First Strategies, LLC
TXU Electric
University of Aberdeen
University of Bath
University of Calgary
University of California
University of Edinburgh
University of Lecce
University of Maine
University of Manchester Inst. Sci. Tech.
University of New Orleans
University of Newcastle
University of North Carolina
University of Pittsburgh
University of Queensland
University of Regina
University of Salvador UNIFACS
University of South Wales
University of Stuttgart
University of Texas
University of Toronto
University of Twente
University of Waterloo
URS Corp
Vattenfall AB
Vattenfall Utveckling AB
W.L. Gore & Associates, Inc.
Washington Power
Wheelabrator Air Poll. Control Inc.
Wisconsin Dept. of Natural Res.
Wisconsin Public Service Corp.
Wolk Integrated Technical Services
World Bank

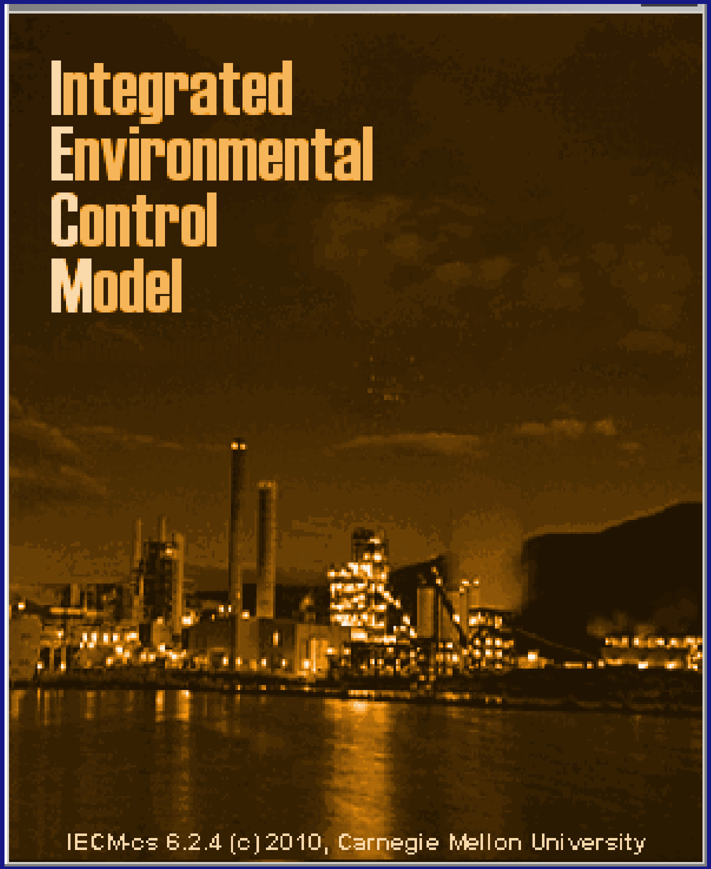
Profile of IECM Users



Model Applications

- Process design
- Technology evaluation
- Cost estimation
- R&D management
- Risk analysis
- Environmental compliance
- Marketing studies
- Strategic planning

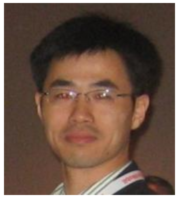
Live Demo of IECM



Work in Progress

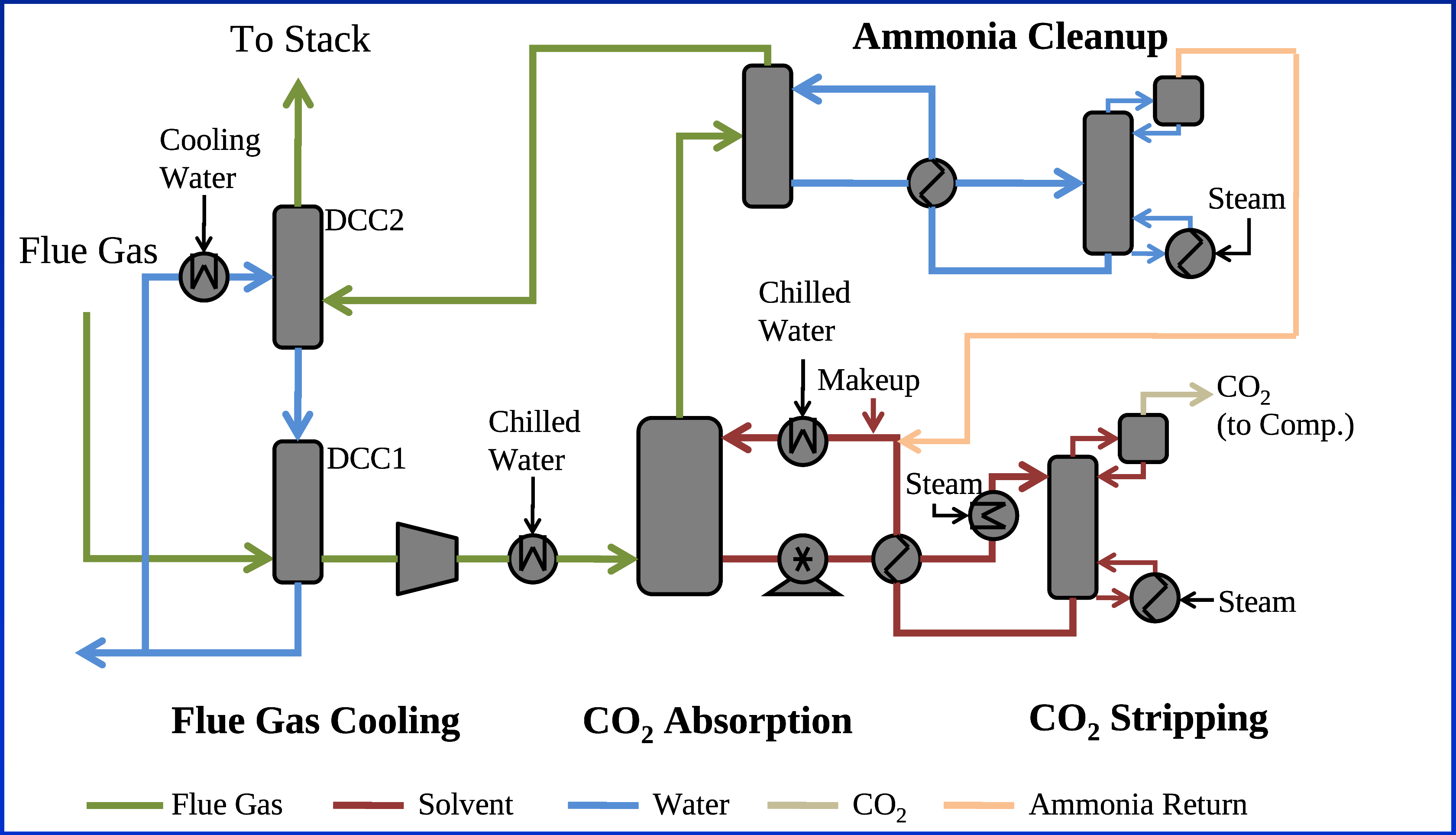
- Performance and Cost Models of Advanced CO_2 Capture Systems
  - Advanced liquid solvents *(Peter Versteeg)*
  - Solid sorbent systems *(Justin Glier)*
  - Membrane capture systems *(Haibo Zhai)*
  - Advanced oxy-combustion *(Kyle Borgert)*
  - Chemical looping combustion *(Hari Mantripragada)*
- Software Development & Dist. *(Karen Kietzke)*
- International Cost Module *(Hana Gerbelova)*







Ammonia-Based CO_2 Capture



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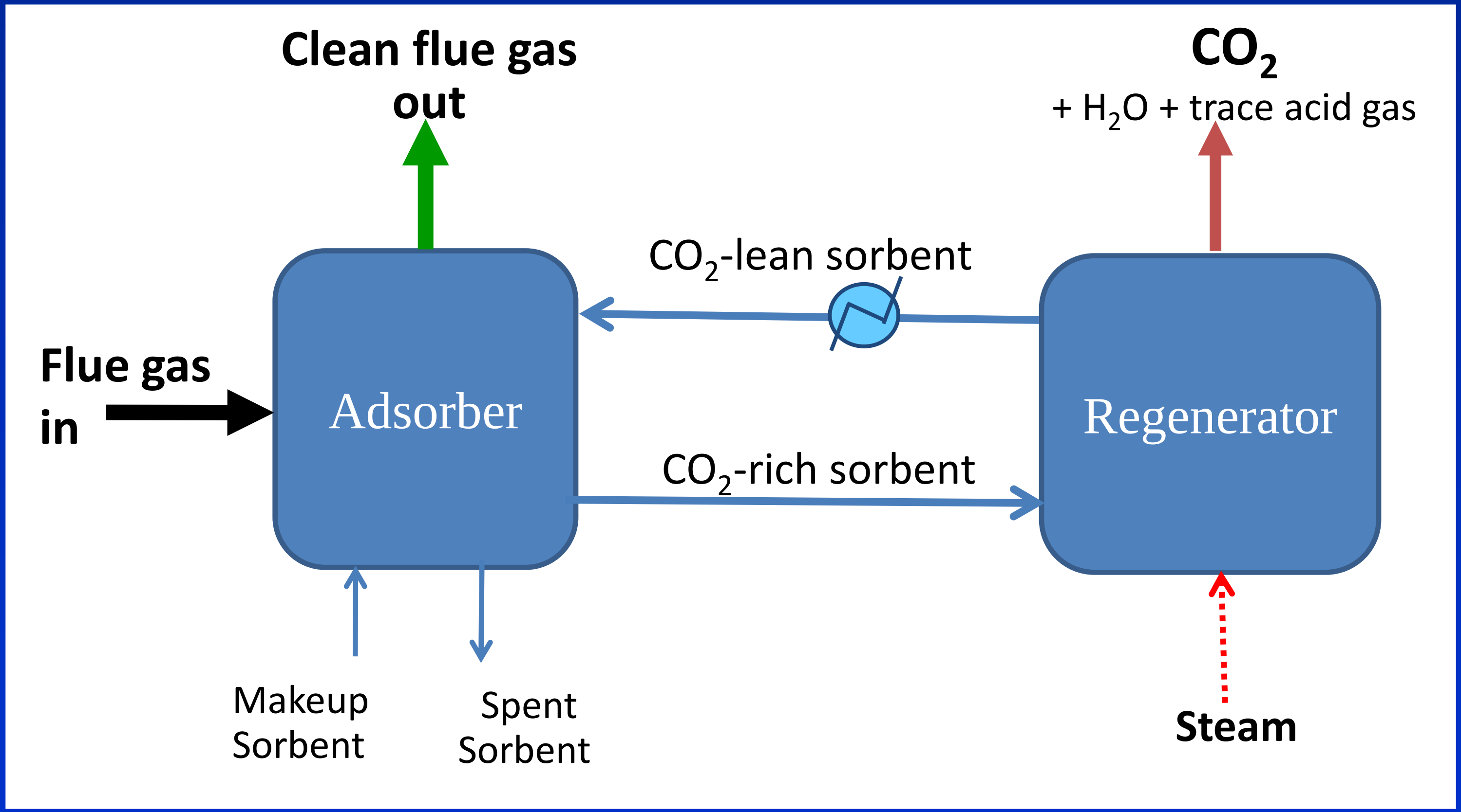
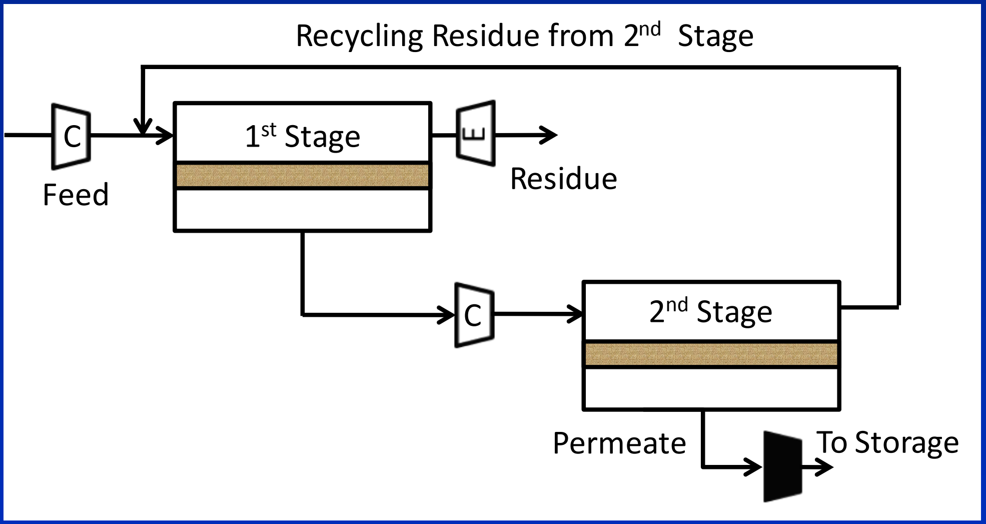
Solid Sorbent Capture System

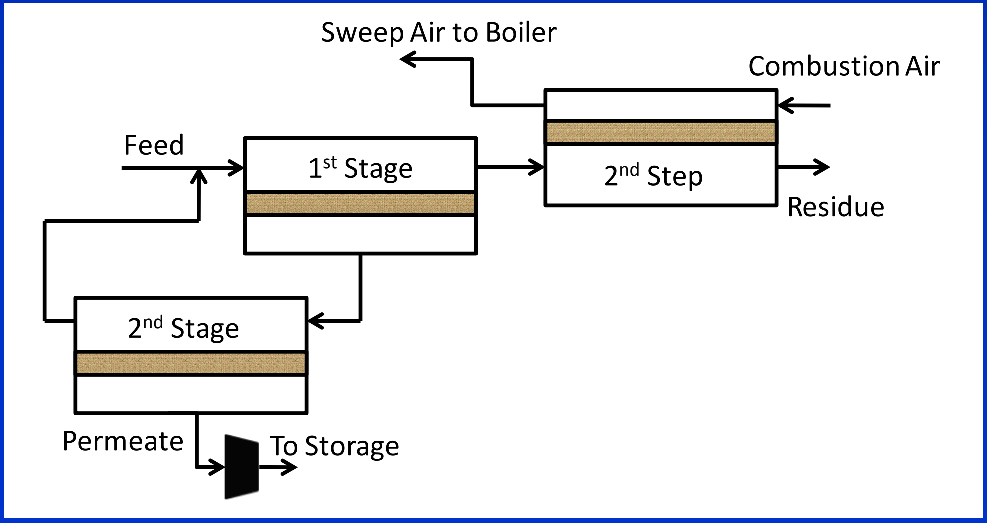


Membrane Capture Systems

Two-stage process
(for post-combustion capture)

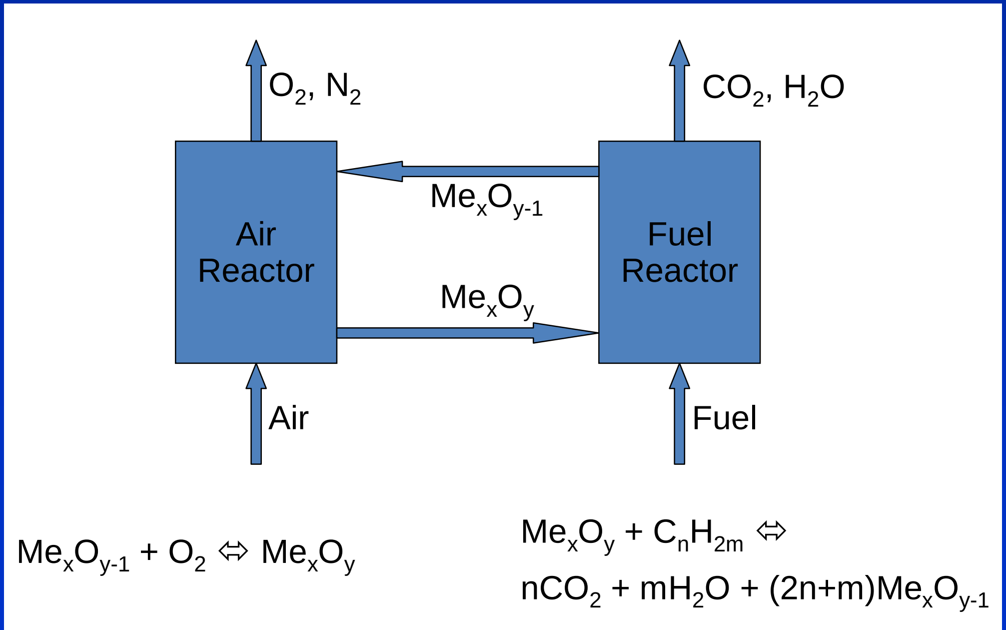


Two-stage process with sweep air

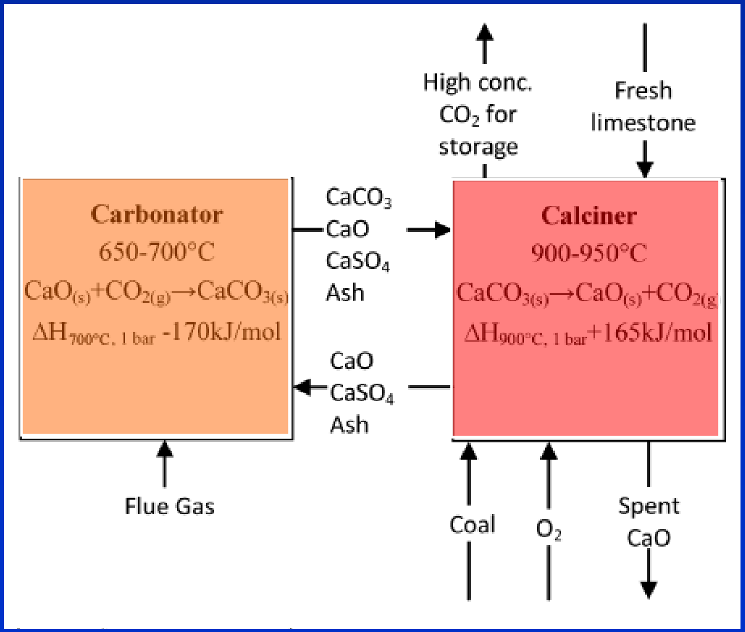


Chemical Looping Combustion

Metal Oxide Looping
(for IGCC systems)

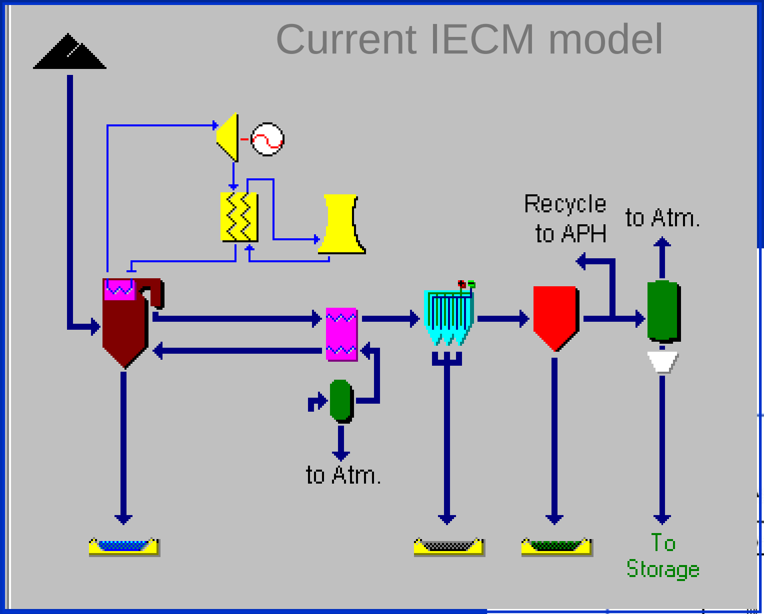


Calcium Looping
(post-combustion systems)

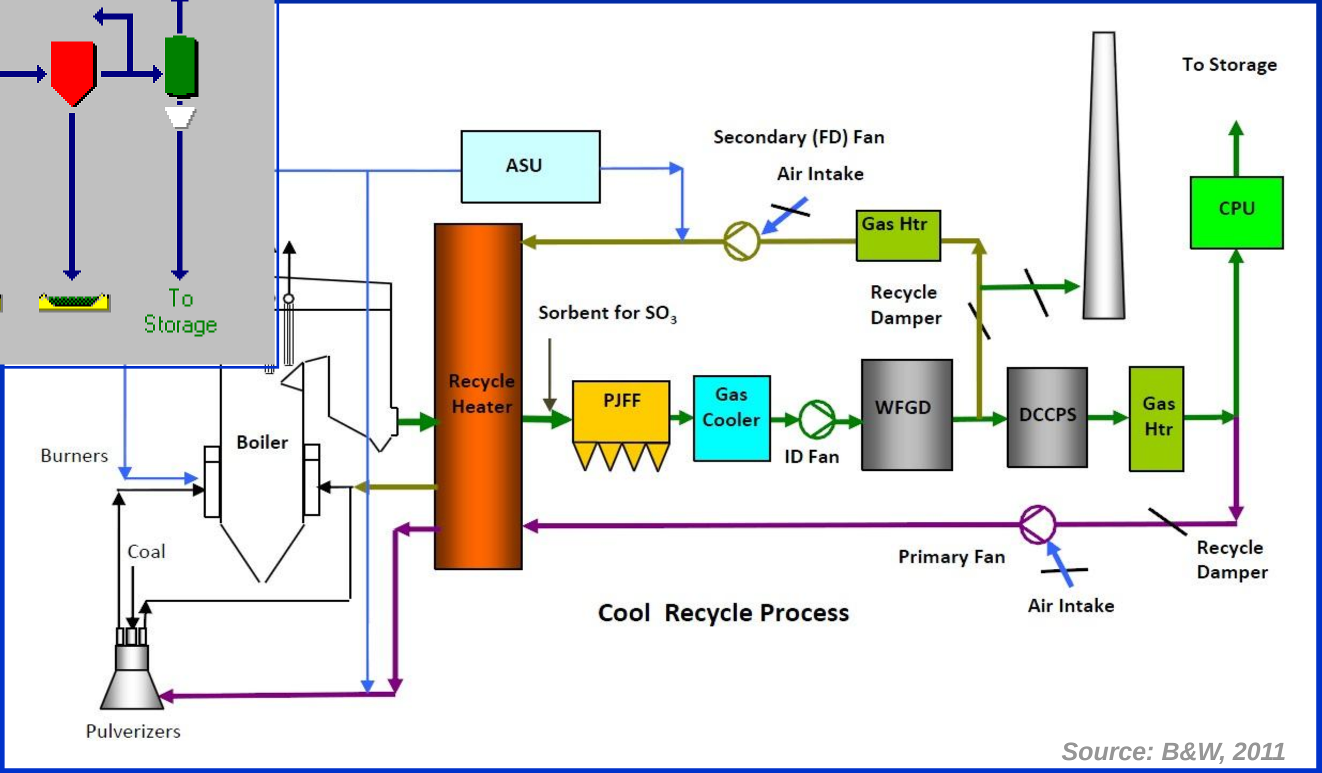


Source: Dean, et al., 2011

Advanced Oxy-Combustion System



One option for advanced design



Project Timetable

- *Fall 2011*: New IECM release with:
  - Beta-version performance and cost models of chilled ammonia process, post-combustion membrane capture, and chemical looping combustion system
  - Other updates and enhancements (e.g., capability for probabilistic *difference* between two uncertain systems)
  - Technical reports and model documentation
- *2012*: Continued model development, including:
  - Preliminary models for post-combustion solid sorbents and advanced oxy-combustion systems
  - Refinements and final release of 2011 beta models
  - New training programs for IECM users

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Special Thanks for Feedback from IECM Users

Two examples from industrial users:

"We've recently started using your IECM website to guide us in developing preliminary cost estimates. ..The information .. is extremely helpful. I just wanted to send along a note of thanks for making this model available and the technical support behind it. We appreciate your work very much."

- Carbon Dioxide Group, ConocoPhillips

"We have been using the IECM model for a few months here at Siemens and it is really useful for our research."

- Corporate Research, Siemens Corporation

www.iecm-online.com

or

www.cmu.edu/epp/iecm

Or contact:

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